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ANOMALOUS PROPAGATION (DUCTING) EFFECTS IN AERONAUTICAL VHF BAND

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Agenda Item:2

SUMMARY

The aim of this paper is to show that, in the context of aeronautical VHF propagation channel, tropospheric refraction may in some cases lead to over the horizon propagation with significant power level. These anomalous propagation conditions otherwise known as ducting conditions may have some impact on design and deployment of VHF digital link system.

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Introduction

The aim of this paper is to show that, in the context of aeronautical VHF propagation channel, tropospheric refraction may in some cases lead to over the horizon propagation with significant power level. These anomalous propagation conditions otherwise known as ducting conditions may have some impact on design and deployment of VHF digital link system.

These ducting conditions are well known at radar frequencies since they happen quite frequently. In VHF band, although meteorological statistics show that they should be less frequent, their probability of occurrence is still important enough to have operational effect on current VHF analog communications.

In France, DGAC has set up an interference observatory which reported in 1997 12 co-channel interference situations (CCI) due to ducting conditions. These interference were observed in ground stations as well as in approaching and landing aircraft, some of these lasted several days.

In the context of DGAC study on VHF aeronautical propagation channel modeling [CHA98], a numerical model for propagation in ducting conditions has been developed at ENAC. This model show that with statistically significant meteorological parameters, received power levels exceeding the sensitivity threshold of current analog VHF receivers (~ -100 dBm) may be obtained at several hundred of km of the transmitter for a range of height going from the ground up to several thousand of meters.

This numerical model confirms the reported interference on VHF analog communications and is able to give significant CCI power level for validation of VDL system.

II. Report of CCI due to anomalous VHF propagation conditions

The table 1 summarizes the reported cases of CCI due to anomalous propagation conditions in France in 1997. The first column lists the VHF receiving station reporting the interference, the second column lists the station transmitting the interference signal on the frequency appearing in column three. The fourth and fifth column shows the localization in space of the interference and the month of year.

Interference reporting station	**Interference transmitting station**	**Frequency**	**Interference spatial localization**	**1997 Month**
Bastia (France)	Alger (Algérie)	121.4MHz	Approaching aircraft	February
St Brieuc (France)	Manchester (United Kingdom)	119.4MHz	Landing aircraft	September
Orly (France)	Heathrow (United Kingdom)	118.7MHz	Approaching, ground taxiing and taking-off aircraft	January
Marseille (France)	Barcelone (Spain)	118.1MHz	Ground Station	March
Aix (France)	? (Germany)	132.5MHz	Aircraft	August
Orly (France)	Limoges (France)	118.7MHz	Ground station	September
Orly (France)	Heathrow (United Kingdom)	128.1MHz	Ground station	April
Lyon Satolas (France)	Palma (Spain)	119.25MHz	Approaching, ground taxiing and taking-off aircraft	September
Brest (France)	Bordeaux (France)	119.025MHz	Ground station	September
Orly (France)	Bornemouth (United Kingdom)	132MHz	Ground station	October
Aix (France)	Heathrow (United Kingdom)	132.625MHz	Approaching aircraft	October
Figari (France)	Rome (Italy)	121.8MHz	Ground station	

Table 1. Reported CCI interference due to ducting conditions in France (SCTA/1997)

III. Theoretical analysis

The fundamental parameter describing large scale refractive effects in troposphere is the refractive index n. In general, n may be computed from the Debye formula [HAL96]:

$$n = 1 + \frac{77.6}{T}\left(P + 4810\frac{e}{T}\right)10^{-6} \qquad (1)$$

Where P (hPa) is atmospheric pressure, T (°K) is temperature, and e (hPa) is water vapor partial pressure. The first (dry) term is due principally to nitrogen and oxygen molecules, while the second (wet) term is from the water vapor molecules. The variations of P,T and e can be considered at various distance scales:

- on the large scale the troposphere is stratified in horizontal layers due to gravity,
- on the medium scale (100 m - 100 km) ground and meteorology can produce spatial and temporal variations,
- on the small scale (<100 m) turbulent mixing causes scattering and scintillation of radio waves

In this paper we are primarily concerned with the large scale refractivity effects. The macroscopic large scale structure of the troposphere varies much more rapidly vertically than horizontally and in practice the same stratification may persist over a horizontal region hundreds of kilometers in extent. Hence in the following we only consider variations of n with height h.

A well known variation with height is the standard average law:

$$n(h) = 1 + 315e^{-0.136h}10^{-6} \qquad (2)$$

With h given in km. In practice however, due to meteorological conditions, the variations of n may be more complex. Because of the closeness of n(h) to unity, it is usual to work with the refractivity N(h) defined by:

$$N(h) = (n(h) - 1)10^{6} \qquad (3)$$

Finally, the modified refractivity M(h) is useful when a flat earth equivalent model is used:

$$M(h) = (n(h) + \frac{h}{a} - 1)10^{6} = N(h) + 157h \quad with \quad a = 6370\,km \qquad (4)$$

In standard conditions, close to the ground, we have using (2): $dN/dh = -39\ km^{-1}$ or equivalently $dM/dh = +118\ km^{-1}$. However, when meteorological parameters (P,T,e) lead to important negative values of dN/dh ($dN/dh < -157\ km^{-1}$ or $dM/dh < 0$) in a layer close to the ground, the situation shown in Fig. 1 may occur. This evolution of M with height is typical of ducting conditions.

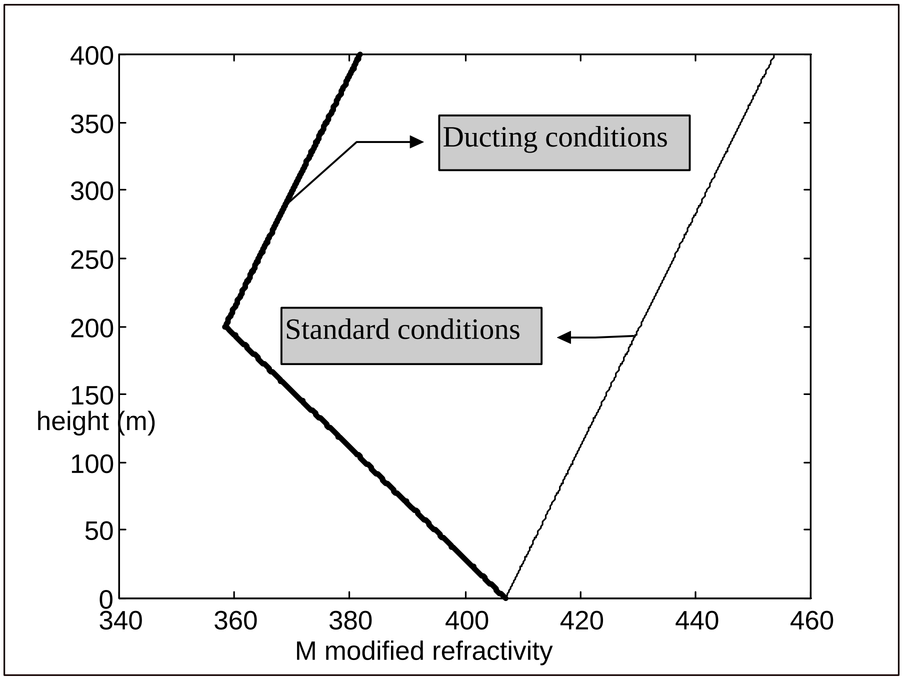

Figure 1. M variation with height

Ray tracing in standard conditions is shown in Fig. 2 and in Fig. 3 with ducting conditions:

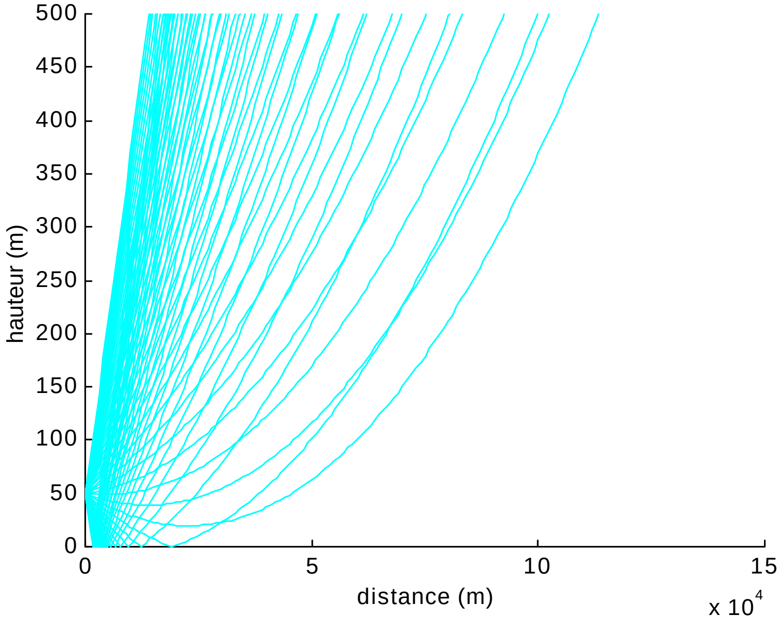

Figure 2. Ray tracing from a transmitter at 50 m height in standard conditions

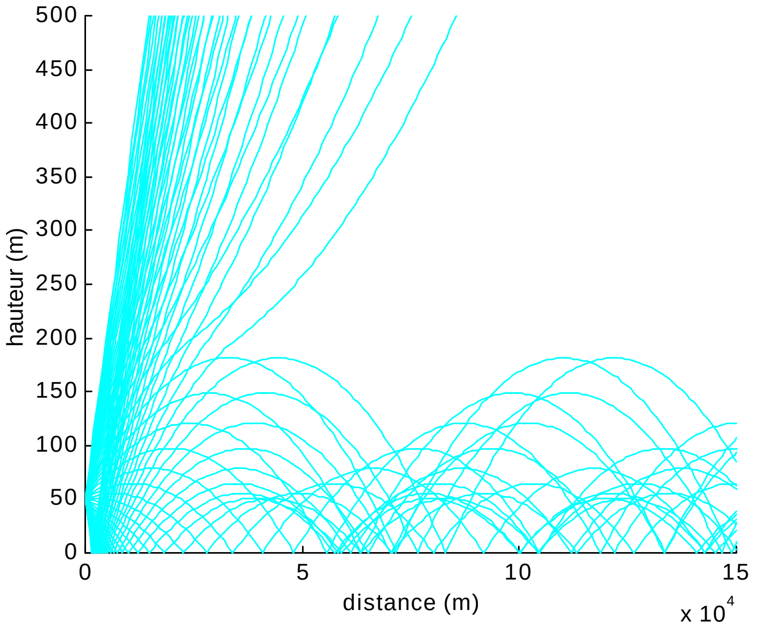

Figure 3. Ray tracing from a transmitter at 50 m height in ducting conditions

For the ducting effect to be efficient, it may be shown that a double condition combining the minimum height h_{min} of the ducting layer as well as the gradient of N through it has to be verified. Table 2 show typical values at 120 Mhz and 3 Ghz:

Frequency (MHz)	$\frac{dN}{dh}$ **(km^{-1})**	**h_{min} (m)**
120	-200	285
120	-400	160
3000	-200	34
3000	-400	19

Table 2. Minimum height and dN/dh values for efficient ducting conditions

It may be seen from table 2 that the minimum necessary height of a ducting layer is less important when frequency augments or when larger negative gradients of N exist. In [CHA98], an analysis of several atmospheric sounding reports showed that a reference ground ducting layer with (dN/dh=-400 km^{-1} , d_{min}=200 m) was possible in France especially in summer and autumn. The following simulation results will use these parameters since they are amenable to VHF ground ducting. It has to be noted that elevated ducting layers may also exist in some situations [HAL96], but they are not discussed in this paper.

IV. Simulation results

A parabolic equation approximation of Maxwell equations based software has been developed to model propagation in heterogeneous ducting conditions [CHA98]. Input parameters are a transmitter of height 50 m radiating 15 W over a smooth dielectric ground with a half-wave vertical dipole and -4 dB losses. The receiving antenna model is also a vertical electric dipole with -4 dB losses.

Figure 4 and 5 below compare the power budget link in ducting, standard and free space (no earth) conditions. It is clear from figure 4 and 5 that the power level observed from horizontal and vertical cuts is much larger in ducting than in standard conditions. One also may note that in these ducting conditions, the power level obtained are similar to free space. This may yield an easy rule of thumb to assess CCI ducting power levels for system considerations. Finally, Fig.4 show that the power decrease with height is quite slow, which confirms reports of CCI due to ducting on approaching aircraft.

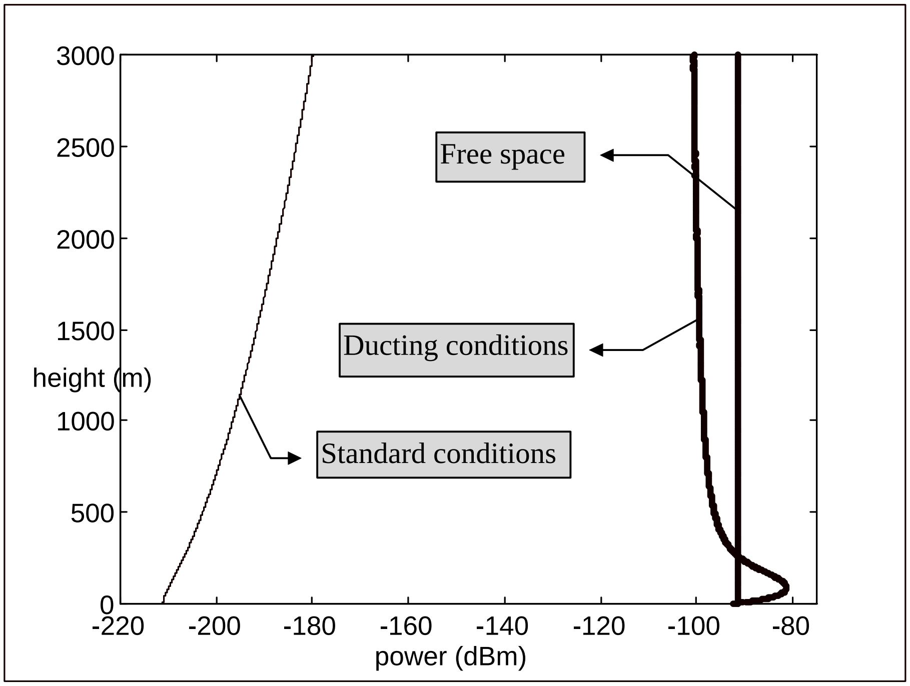

Figure 4. Ducting Layer (200m, -400N/km), vertical cut at 600 km from the transmitter

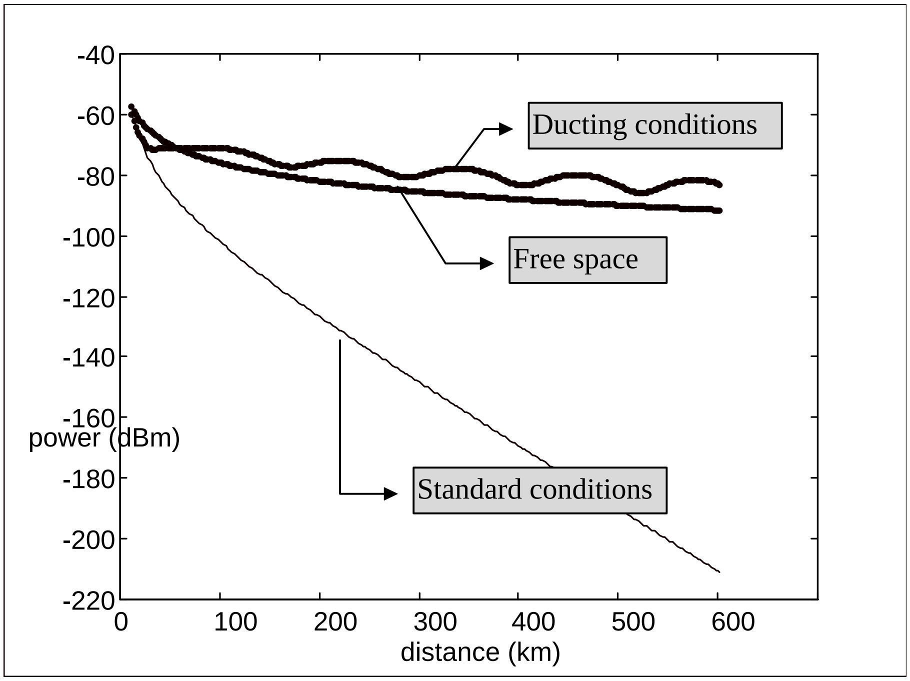

Figure 5. Ducting Layer (200m, -400N/km), horizontal cut at 50 m height

V. Conclusion

In this paper it has been shown that a reference ground ducting layer of 200 m height with dN/dh= -400 km^{-1} vertical gradient may lead to over the horizon co channel interference in VHF band. The stronger interference power levels are obtained close to the ground (inside the ducting layer), but the decreasing with height is quite slow, explaining why approaching planes at elevated altitudes may also report these interference.

Although the meteorological parameters leading to theses ducting conditions are less frequent in VHF band than at higher frequencies, reports of interference due to this mechanism in current VHF analog band show that this kind of CCI will also exist for VHF Digital Link.

The members of the group are invited to note the information presented in this paper.

VI. Bibliography

[CHA98] B. Château, "VHF Propagation Channel Modeling for Aeronautical Mobile Communications", PhD report (in French), Toulouse, 07 Oct. 98.
[HAL96] M.P. Hall, "Propagation of radio waves", IEE 1996.